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DNA 4059T

ON NUCLEAR HEIGHT-OF-BURST AIRBLAST AT HIGH OVERPRESSURE

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P.O. Box 9695
Marina del Rey, California 90291

January 1975

Topical Report

CONTRACT No. DNA 001-75-C-0057

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Prepared for
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: DNA 4059T
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): ON NUCLEAR HEIGHT-OF-BURST AIRBLAST AT HIGH OVERPRESSURE
5. TYPE OF REPORT & PERIOD COVERED: Topical Report
6. PERFORMING ORG. REPORT NUMBER: RDA-TR-5900-015
7. AUTHOR(s): H. J. Carpenter
8. CONTRACT OR GRANT NUMBER(s): DNA 001-75-C-0057
9. PERFORMING ORGANIZATION NAME AND ADDRESS: R & D Associates, P.O. Box 9695, Marina del Rey, California 90291
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NWED Subtask P99QAXDB001-13
11. CONTROLLING OFFICE NAME AND ADDRESS: Director, Defense Nuclear Agency, Washington, D.C. 20305
12. REPORT DATE: January 1975
13. NUMBER OF PAGES: 26
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS (of this report): UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results of a brief review and evaluation of height-of-burst (HOB) airblast environments produced by nuclear weapons, with emphasis placed on the high overpressure side of the thermal precursor shock envelope, are presented. It is concluded that no significant precursors will be formed at and above the 1000 psi overpressure level for any value of weapon yield or height-of-burst, and that blast environment prescriptions for ideal surfaces may be used with acceptable confidence for bursts over thermally

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20. ABSTRACT (Continued)

non-ideal surfaces in this overpressure range. It is concluded further that no degradation in the values of airblast kill mechanisms with respect to ground burst values should occur over a substantial portion of the shins of the HOB curves at and above 1000 psi.

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SECTION 1. INTRODUCTION

One of the scenarios considered in the kill of hard targets with nuclear weapons includes the allocation of two warheads to a single target to assure acceptable probability of success (a two-on-one engagement). The difficulty of achieving simultaneous detonation of the two weapons while precluding fratricide by neutrons and airblast argues for the delay of arrival and detonation of one weapon relative to the other. If both are to be surface-contact bursts, the timing for the second burst becomes a critical element of the strike because of the potential fratricide and aimpoint dispersion produced on the second reentry vehicle by crater ejecta, airblast, dust, etc., from the first detonation. Other scenarios of some interest also call for minimization of dust lofting from the ground's surface. Therefore, measures are sought to minimize or eliminate problems of fratricide, CEP dispersion, and dust lofting.

One approach for the two-on-one hard target attack is to detonate the first weapon above the earth's surface at a height sufficient to eliminate crater ejecta and minimize the rising dust cloud effects. With this accomplished, the second burst could be delayed so as to render negligible the close-in blast loads or the dispersive effects of blast winds on the second RV. Such a tactic results in the loss of crater ejecta and crater-induced ground motion as part of hard target kill effects for the air burst. The question of how the surface-level airblast varies with height-of-burst (HOB) must be addressed in evaluating the effectiveness of this approach, since the blast will produce the major weapon effects remaining for the elevated burst--direct airblast loading and airblast-induced ground shock.

This paper presents the results of a brief analysis of the surface-level airblast between 500 and 3000 psi peak overpressure. Curves are derived from small-scale HE experiments which predict that peak overpressure is not diminished for substantial heights-of-burst above ideal surfaces from that produced by a surface burst at equal ground range; and indeed, there may be some enhancement with height. This conclusion is believed to apply also for non-ideal surfaces above the ~800 psi peak overpressure level because no substantial thermal shock precursor is evident in the data from 1-70 kiloton nuclear tests over desert-type surfaces. It is argued here that this observation would be true also for megaton bursts over non-ideal surfaces. Theoretical and experimental work being conducted by the Defense Nuclear Agency is expected to corroborate these arguments.

Equally if not more important than peak overpressure to hard target kill is the overpressure impulse loading delivered in the early part of the blast wave characteristic of target response time. Estimates based on nuclear data at lower overpressure levels and evidence from chemical explosive experiments and analytical calculations indicate that overpressure impulse should behave in a manner similar to that of peak overpressure with height-of-burst.

SECTION 2. SUMMARY COMMENTS

1. On the basis of our best-estimates we conclude that at and above 1000 psi the overpressure or crushing airblast in general will not be degraded from that of a surface burst for heights-of-burst sufficient to eliminate crater ejecta and minimize dust lofting for both ideal and non-ideal surfaces. This conclusion is dependent somewhat upon the target structure design and details of the overpressure waveform, each of which should be considered in the assessment of specific cases. The general conclusion can be substantiated with high confidence for bursts above ideal surfaces because of recent HE experiments. The following comments support this conclusion for bursts over non-ideal surfaces.

2. Available nuclear data and theory lead to the conclusion that significant thermal precursors will not form at and above the 1000 psi peak overpressure level for kiloton- or megaton-size nuclear bursts. Therefore, peak overpressure and overpressure impulse values applicable to ideal surface conditions are expected to apply to non-ideal surfaces as well, at these high overpressures. Strong precursors will form over non-ideal surfaces below ∿800 psi, reducing the applicability of ideal surface blast data there. (Megaton-size bursts are expected to show the existence of precursed waveforms to larger scaled ground ranges than those shown by the precursor envelope currently used; but at the high pressure end of this envelope, they may cause less precursor action than kiloton bursts.) Thus, the peak overpressure isobars presented herein may be used for ideal as well as real surfaces at and above 1000 psi, with the realization that some small shrinkage toward ground zero may occur over real surfaces. <u>However, the reader should not use these peak overpressure curves from which to develop peak dynamic pressure curves via the Rankine-Hugoniot relations in the Mach region</u>. Based on these curves, no degradation in peak overpressure with respect to a ground burst is expected to occur over a large portion (about the upper 1/2) of the shins of the overpressure HOB map at and above 1000 psi. We have no reason to expect the peak overpressure in the lower one-half of these shins to be degraded below that of a surface burst.

3. While nuclear experimental data are not adequate for construction of overpressure impulse curves above about the 300 psi peak overpressure level except by extrapolation, the available data and Brode's analytical model indicate that the impulse will not be diminished in the Mach region below that of a surface burst. In fact, there might be an enhancement with HOB. Data from 8-lb charge HE experiments indicate that this enhancement might be increased for that portion of overpressure impulse delivered in the early portion of the blast wave, and most applicable to hard target kill.

4. Experimental and theoretical research being conducted by the Air Force Weapons Laboratory and contractors under DNA auspices is relevant and important for the construction of ideal surface overpressure impulse and dynamic pressure curves. These studies may also help to confirm or improve the conclusions drawn here with respect to thermal precursor shock envelopes. Further, they may provide a quantitative description of precursor flows.

SECTION 3. PEAK OVERPRESSURE

Airblast measurements taken during the atmospheric nuclear test program were insufficient to fully define HOB blast parameters above about 200 psi shock overpressure [1]. Approximations have been used to develop HOB curves up to 10,000 psi overpressure [2,3]; however, in each case the authors state that some guesswork was used in constructing the curves. Unpublished finite-difference computer calculations made with the SHELL hydrocode at the Air Force Weapons Laboratory were not finely enough zoned nor sufficient in number to define accurately the HOB curves. (A new set of finely zoned calculations is being run.) Recent high-precision experiments [4,5] performed for the Defense Nuclear Agency with 8-lb spheres of PBX-9404 explosive permit development of peak overpressure HOB curves applicable to nuclear explosions over ideal surfaces up to a few thousand psi. The isobars shown in Figure 1 were synthesized from the 8-lb charge data and the nuclear free air burst pressure-range curve, supplemented by theory in the regular reflection region. The zero burst height point shown on each curve was obtained by doubling the energy of the nuclear free air curve. Figure 1 assumes a perfectly reflecting, planar earth (ideal surface). Clearly, for this condition a given peak overpressure can be produced with bursts at heights in the upper portion of the Mach region (shin of the curve) at the same ground range as it can with a surface burst. Above the 1000 psi level, a small range increase over the surface burst value might be achieved by bursts at selected heights.

The next question is whether or not a thermally non-ideal surface, characteristic of most missile sites, would result in appreciable modification of these ideal surface isobars. Nuclear tests indicate that, in the overpressure region at and below ∿500 psi, a precursor shock forms over desert and asphalt surfaces [1]. This precursor shock results from a heated layer developed near the ground surface by fireball radiation prior to shock arrival. Its effect is to modify the blast wave strongly, lowering peak overpressure and increasing the peak dynamic pressure. The nuclear

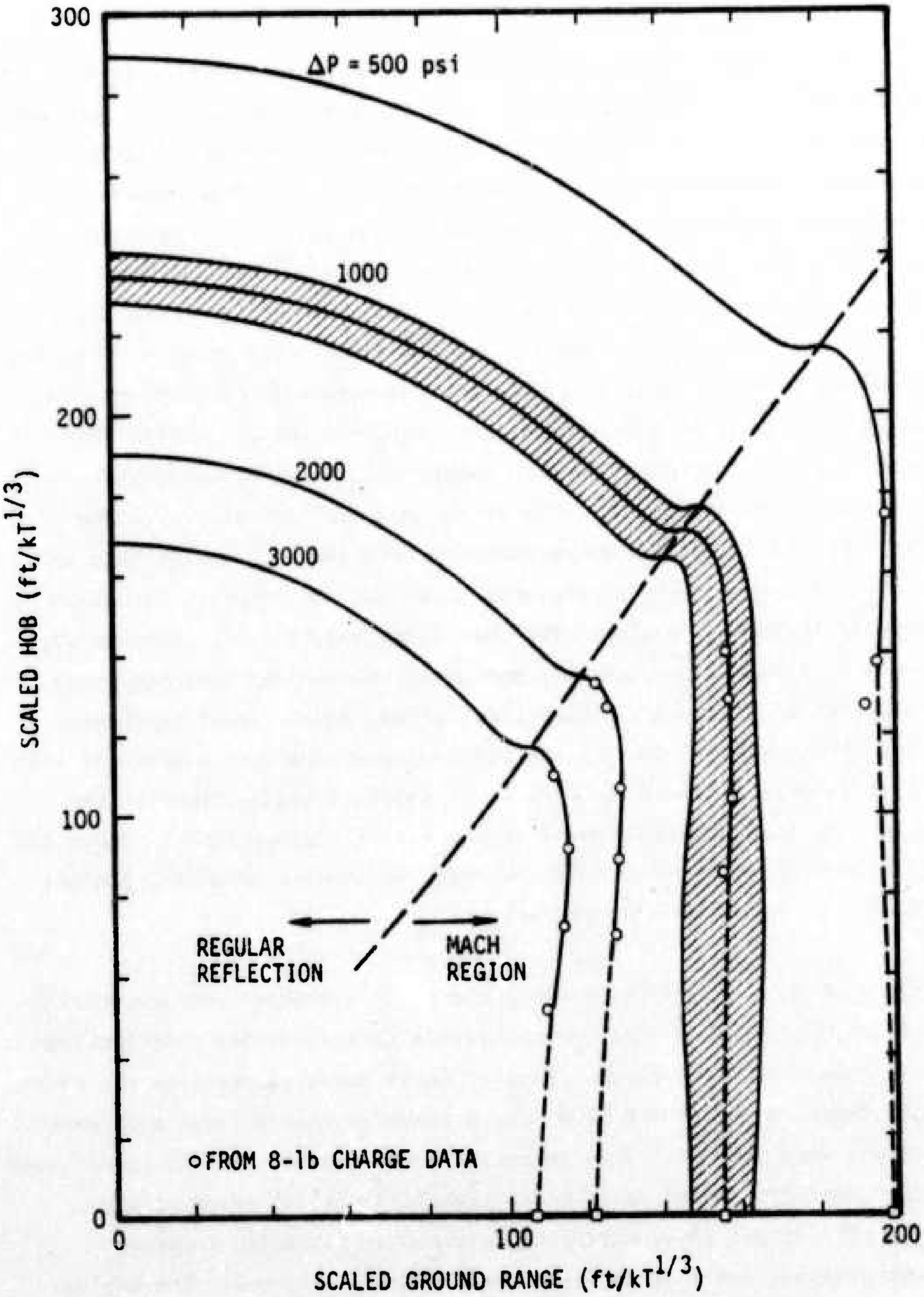

Figure 1. HOB Curves for Peak Overpressure

data were used to develop a long established HOB space envelope inside of which precursors will form and outside of which no precursors are expected to form (Figure 2). The area of interest in this paper is the lower left corner of the precursor envelope. Based on a recent review of the data, the dot-dashed line is proposed as the left side of the precursor boundary, replacing the previous solid line boundary specified in Effects Manual I [6]. The shots used to determine this boundary all were made over dusty desert surfaces conducive to strong precursor formation. (Shot yield, HOB, and location are indicated on the figure.) A point from shot SMALL BOY has been added to the old data, which suggests that the boundary moves to larger range below 100 feet HOB. The boundary suggested here was based on precursor length measurements corroborated by shock arrival time and peak overpressure measurements. Waveform Types I and V are unprecursed and classical, while Types II-IV are precursed. Figure 3 shows the new precursor boundary superimposed on the HOB curves of Figure 1. One sees that above $\sim$800 psi, no precursor should be formed for kiloton-size bursts over reasonably planar, real surfaces. (Asphalt-covered surfaces produce extremely strong shock precursors. If a relatively large area of asphalt should surround the target, then the precursor boundary could move to higher overpressure levels.) We see also from Figure 3 that the new curves indicate somewhat less range coverage than Brode's curves.

The question remains: Will megaton-size bursts exhibit the same precursor characteristics as kiloton bursts on a scaled basis (i.e., distance, time $\sim$ (yield)$^{1/3}$), or will the precursor boundary change significantly? Available nuclear data from megaton explosions are insufficient to guide us here. To obtain an answer, we turn to a comparison of the hydrodynamic and thermal radiation characteristics of nuclear weapons. While the hydrodynamics (shock, time of arrival, distances, etc.) scale as the 1/3 power of the yield, the time distribution of thermally radiated power scales as about the 1/2 power of yield. This difference in scaling results in a non-similarity, with varying explosive yield, between the hydrodynamic geometry and the thermal energy received at the earth's surface prior to

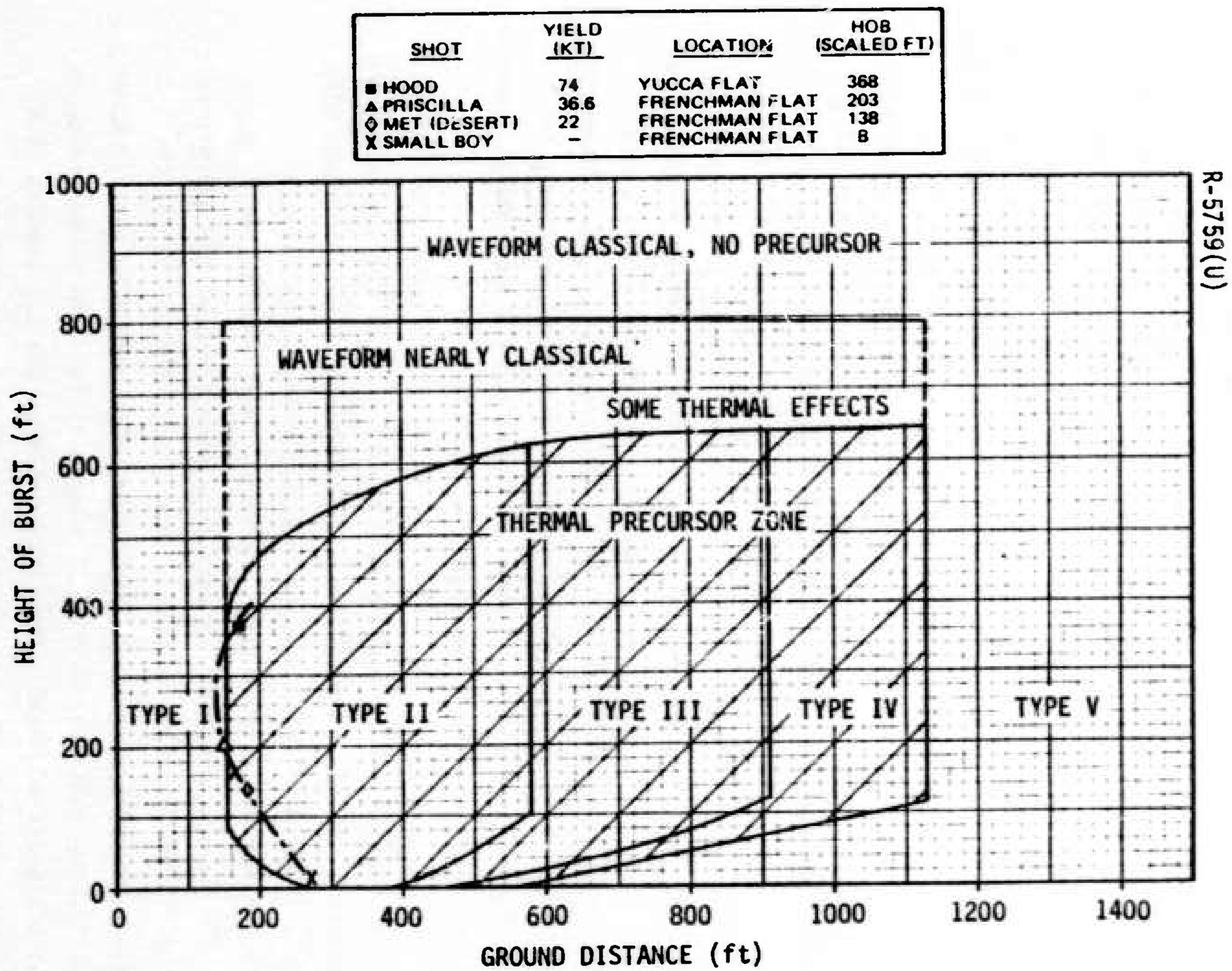

Figure 2. Variation of Overpressure Waveform from a 1 kT Explosion Over a Thermally Non-Ideal Surface

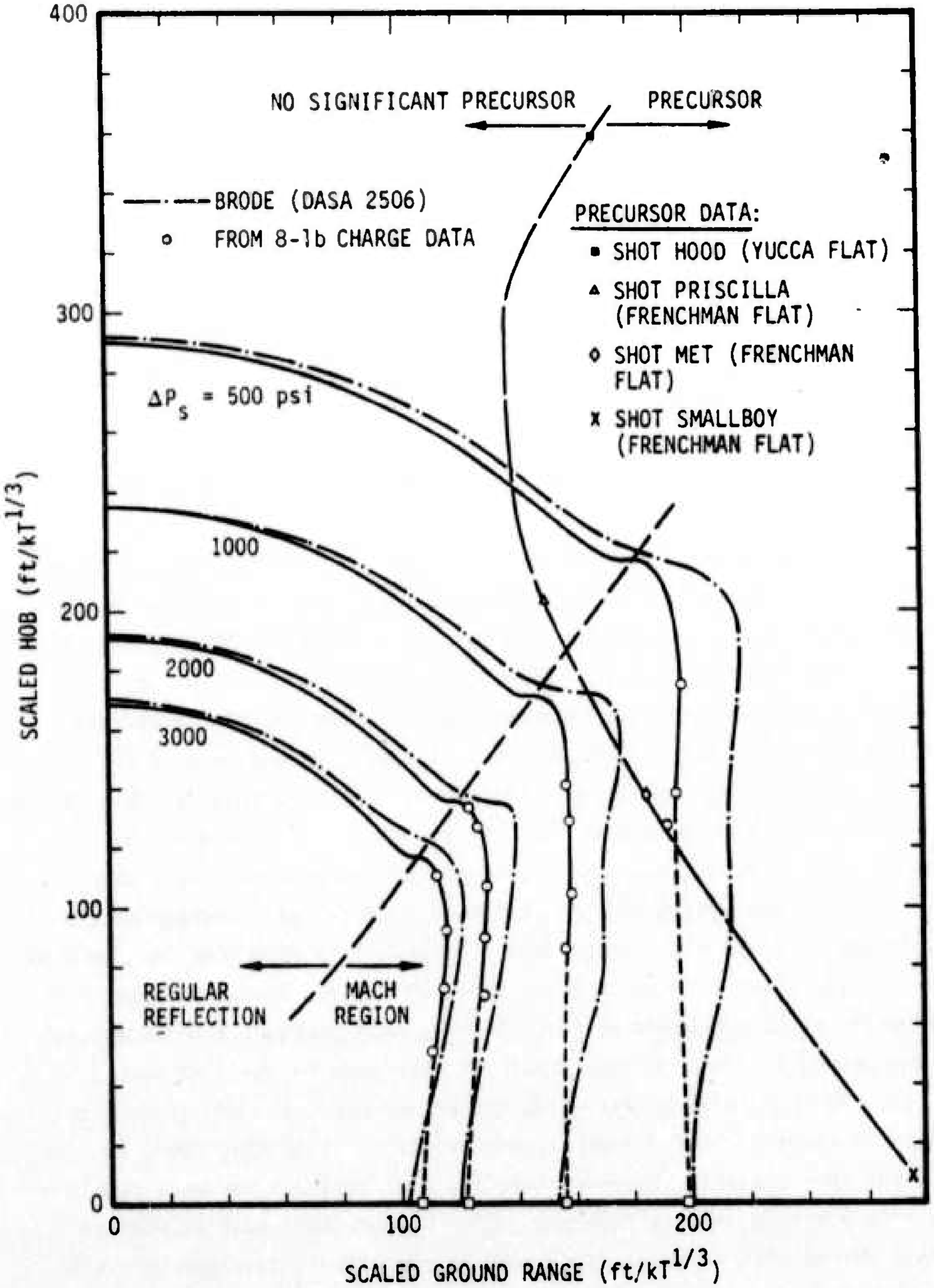

Figure 3. Precursor Boundary Overlaid on HOB Peak Overpressure Curves

air shock arrival. If this preshock energy is responsible for producing the shock precursor, then a comparison of the kiloton and megaton values can be instructive.

Figure 4 shows the fireball radiant energy fluence, Q_{RS}, incident to the ground surface up to the time of air shock arrival (on an ideal surface) for 1 kT and 1 MT bursts at 150 ft/kT$^{1/3}$ HOB. Note that for the scaled range at which a precursor would develop in the 1 kT explosion (∿178 feet), Q_{RS} for the 1 MT case is 42 cal/cm^2 or only 1.5 times that of the 1 kT fluence at that location; yet the size of the 1 MT blast wave, i.e., the physical and temporal wavelength and the height of the Mach stem, is 10 times that of the 1 kT wave according to cube-root hydrodynamic scaling.

If somehow the heated layer for the 1 MT explosion were no thicker on an absolute basis than that for the 1 kT explosion, the temperature increase in the layer could be 1.5 times that for the 1 kT case. This would result in a maximum increase in layer sound speed of 23% over that of the 1 kT case and a somewhat stronger precursor shock. However, the relatively small thickness of this layer and the size of the precursor produced would influence a far smaller portion of the 1 MT wave than it would for the 1 kT wave. (Looked at another way, the advancing blast wave can be thought of as a moving pressure reservoir and the precursor as a slot or orifice in the bottom of that reservoir through which leakage occurs. The fraction of the shock front area represented by this slot for the 1 MT case is only about 1/10 of that for the 1 kT layer. Therefore, the influence of the precursor on the main wave peak pressure drop at points on the ground in the 1 MT case should be less than in the 1 kT case.) So, even in this extreme case, significant overpressure reduction is not likely to occur at higher overpressure levels for 1 MT than for 1 kT. It does not seem possible, however, that the 1 MT heated layer will remain the same absolute size as that for 1 kT. Measurements made on nuclear events showed that no detectable preshock pressure is developed beneath the heated layer, indicating that full expansion of the heated air occurs as the heat is added. Under this condition the 1 MT layer should expand to about 1.5 times the depth of the 1 kT layer at the

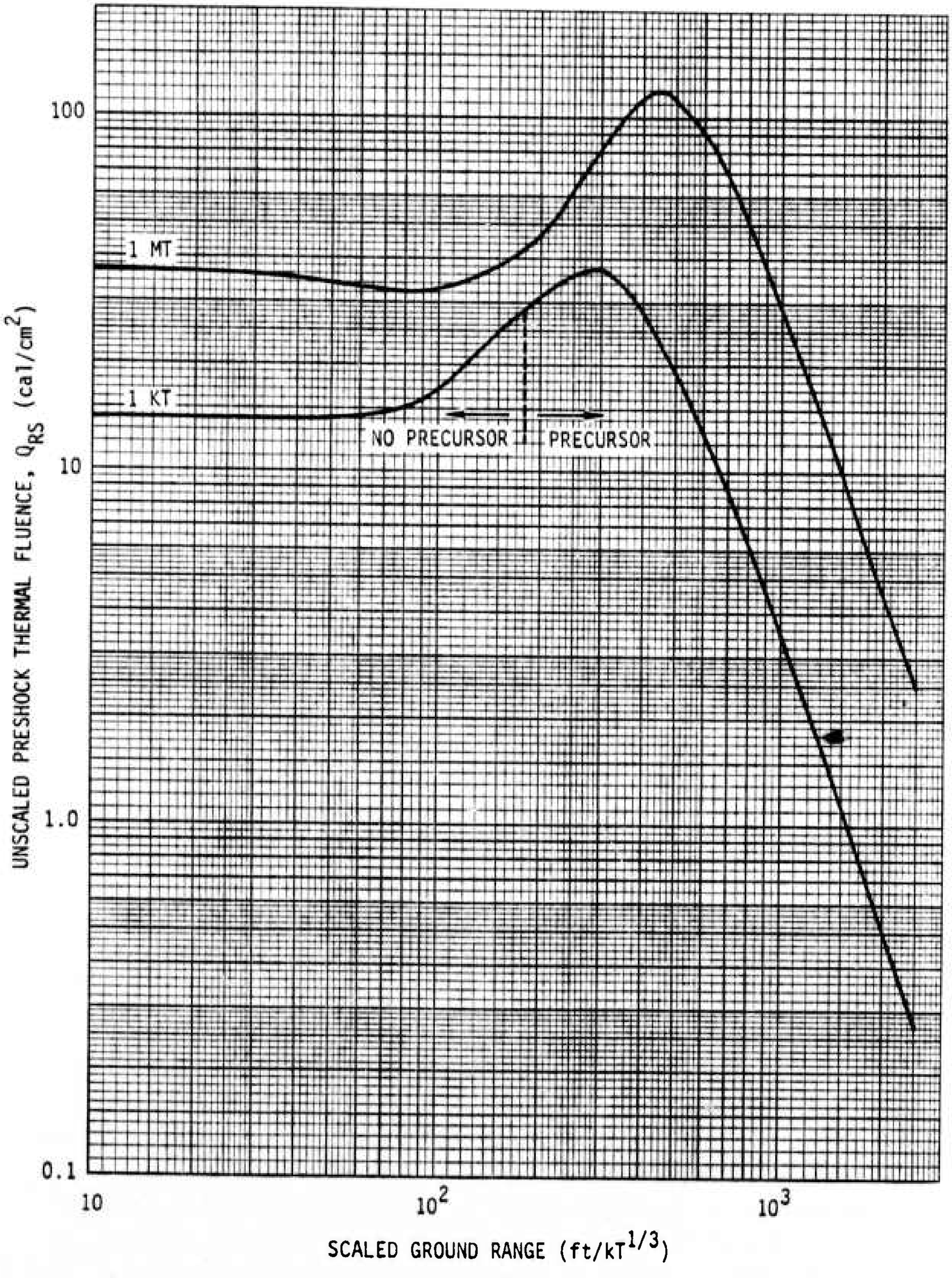

Figure 4. Thermal Fluence at Shock Arrival vs Ground Range, 1 kT and 1 MT at 150 ft/kT$^{1/3}$ HOB

scaled range under discussion. The resulting layer temperature would be about the same as or lower than that in the 1 kT layer. This alone would require that the 1 MT precursor not form at shorter scaled ranges, plus the relative size of the layer would still be only ~1/7 that for 1 kT. An additional consideration for the 1 MT case is that the radiant energy is delivered to the surface more nearly uniformly in time and over a 10 times greater time period than that for the 1 kT case (250 ms vs. 25 ms at 178 scaled feet). This would tend to disperse the 1 MT layer more, and further reduce its temperature. Therefore, it seems impossible for the heated layer along the ground surface to be as important to the 1 MT blast wave as it is to the 1 kT wave at the high pressure side of the precursor envelope.

The above argument can be made with equal applicability for other heights-of-burst in the high overpressure region of interest here. The author's best judgment, then, is that significant precursors will not form in megaton bursts over realistic missile sites above the ~800 psi level. Referring again to Figure 4, we see that the radiant energy fluence peaks at greater scaled ground range for 1 MT than for 1 kT and reaches ~9 times that for 1 kT at ~700 feet scaled range. It increases gradually to a ratio of 10 for greater ranges. Since there exists some threshold of preshock thermal fluence below which precursor action cannot occur (say, 10 cal/cm^2), megaton bursts may exhibit precursed waveforms to somewhat larger scaled ranges (lower overpressure) than kiloton bursts prior to returning to classical waveforms.

Based on the above analysis, it is concluded that the peak overpressure curves presented in Figure 1 for 1000 psi and above are applicable to both kiloton- and megaton-size nuclear explosions over the real surfaces representative of most missile sites. Although these curves were developed for an ideal surface, real surface effects should result in only small decreases in range to a given overpressure level. Note the band of uncertainty about the 1000 psi curve. This band, which includes uncertainties in defining the ideal surface case as well as an allowance for thermal effects, should be typical of the curves above 1000 psi taken as a percent of range. Below about 800 psi, a significant precursor shock would begin to form which would tend to round off the upper portions of the peak overpressure HOB curves. Experimental and computational research is being conducted by the Defense Nuclear Agency to define precursors at high overpressures. That very pertinent research, being performed by the Air Force Weapons Laboratory and DNA contractors, is expected to be useful in evaluating the above conclusions.

SECTION 4. OVERPRESSURE IMPULSE

As indicated earlier, the fraction of overpressure impulse delivered during the time of target response is important in estimating target kill. If this impulse is not diminished with respect to that from surface bursts for heights of burst well above heights which do not produce ejection craters (≳25 feet/kT$^{1/3}$ HOB), then the overpressure kill mechanism can be as effective as for surface bursts and ejecta/dust lofting minimized. As with peak overpressure, nuclear data permit construction of positive phase overpressure impulse curves up to only the 200 psi level (∿2.5 psi-seconds for 1 kT), with some data points available for 3.0 psi-seconds and 4.0 psi-seconds, or about the 300 and 500 psi overpressure levels, respectively [1]. The data show a complex variation of impulse with HOB; but, in general, the thermally non-ideal surface (precursed) curves show an increase in total impulse over that of the near-ideal curves in the vicinity of the knee of the peak overpressure curves. All these data lie well within the precursor region for non-ideal surfaces and can be used only as a basis of judgment for extrapolating to shorter ranges (higher overpressure levels). The available curves, being for total overpressure impulse, do not provide quantitative information as to impulse delivered at early times appropriate to hard target response. They provide only a rough indication as to the trend of what one might expect to occur.

The most consistent application of the nuclear data to provide an indication of the non-precursed impulse isobars at 1000 psi and above is to use the near-ideal surface curves, since no absolutely ideal surface data are available from nuclear tests. Such curves along with the data points from which they were drawn are reproduced in Figure 5. Note that the preparers chose to ignore the data point at 500 feet HOB for the 1.5 and 2.0 psi-seconds cases. If these points are considered, the curves might just as well have been drawn as shown by the dashed lines, showing substantial range increase with HOB. Even if the solid lines are correct, the total impulse does not diminish below the surface burst value as HOB is increased

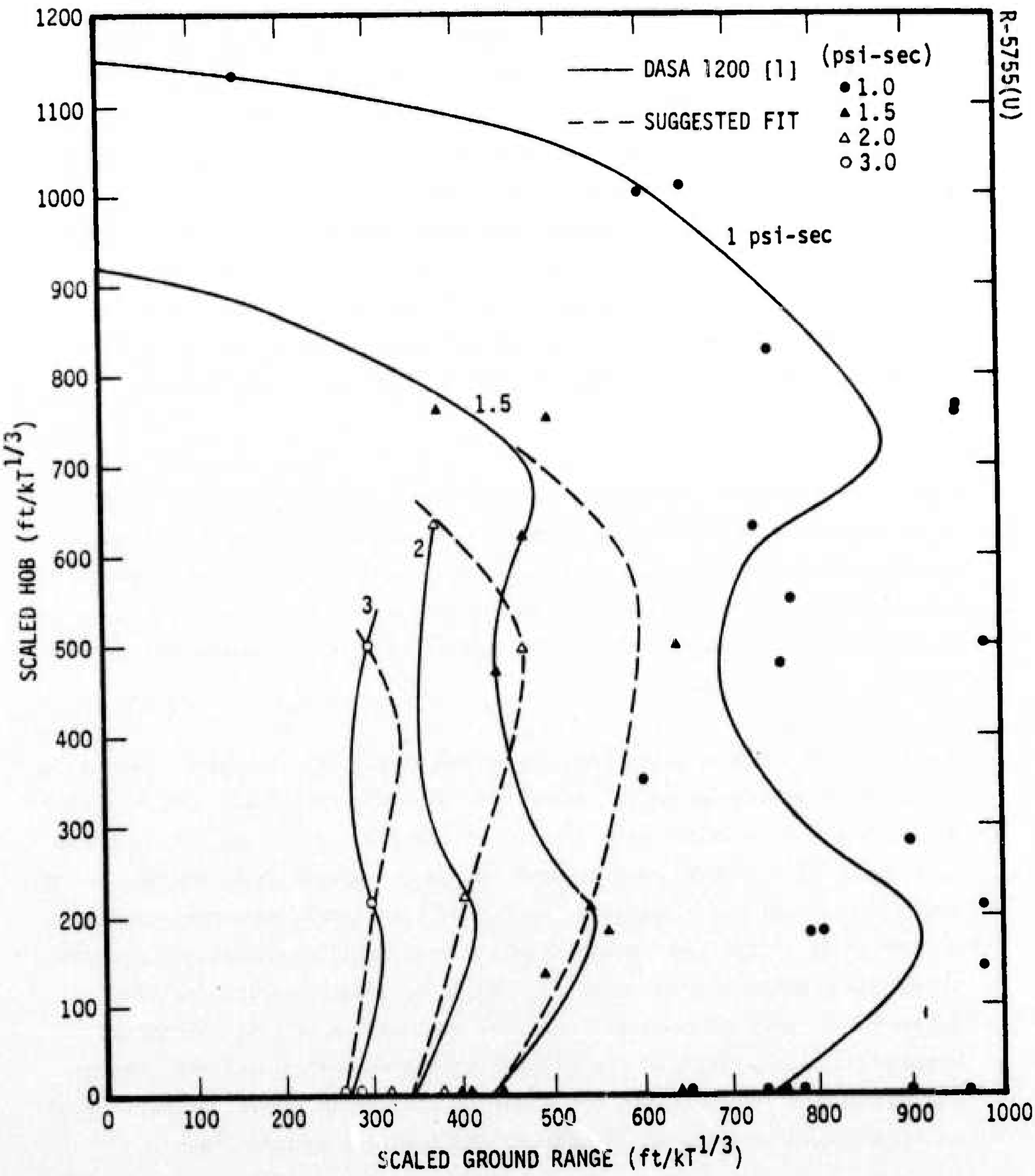

Figure 5. HOB Curves for Positive Phase Overpressure Impulse from Nuclear Tests Over Near-Ideal Surfaces

to and above values equal to the ground range. While we expect this to hold true at higher overpressure values, it is highly desirable to have confirming experimental data. We have only HE data available above 500 psi, such as the small charge data used in developing the peak overpressure curves. It is not clear at this time that these data can be used legitimately to produce HOB impulse curves applicable to the nuclear case. However, the total impulse curves resulting from direct plotting of the data show small (∿10%) but definite increases of impulse with HOB from about the 150 to 2000+ psi levels. Due to the high precision and high level pressure measurements of the experiments, we shall continue to investigate the 8-lb charge HE data for application to the nuclear case.

Brode [3] has prepared a set of impulse curves (Figure 6) which extend to 30 psi-seconds (above 10,000 psi peak overpressure). These curves were derived from pressure-time curves developed analytically to meet reasonable boundary conditions. While the pronounced knees shown below about 4 psi-seconds seem unrealistic, the curves appear well-behaved above the 5 psi-seconds (∿700 psi) level.

Based on the evidence cited here, it seems reasonable to expect that total positive phase impulse at and above 1000 psi will not diminish with respect to surface bursts in the Mach portion of the HOB curves, and may increase somewhat. Furthermore, experimental evidence suggests that impulse in the early portion of the blast wave typical of hard target response times (say to the point of 1/2 peak overpressure) might exhibit considerably greater enhancement with HOB than those for the total positive phase impulse. However, not only the impulse, but also the details of both the target structural design (such as its natural vibration period) and the loading overpressure waveform can be important in predicting target failure. Such details should be included in failure analyses for specific cases.

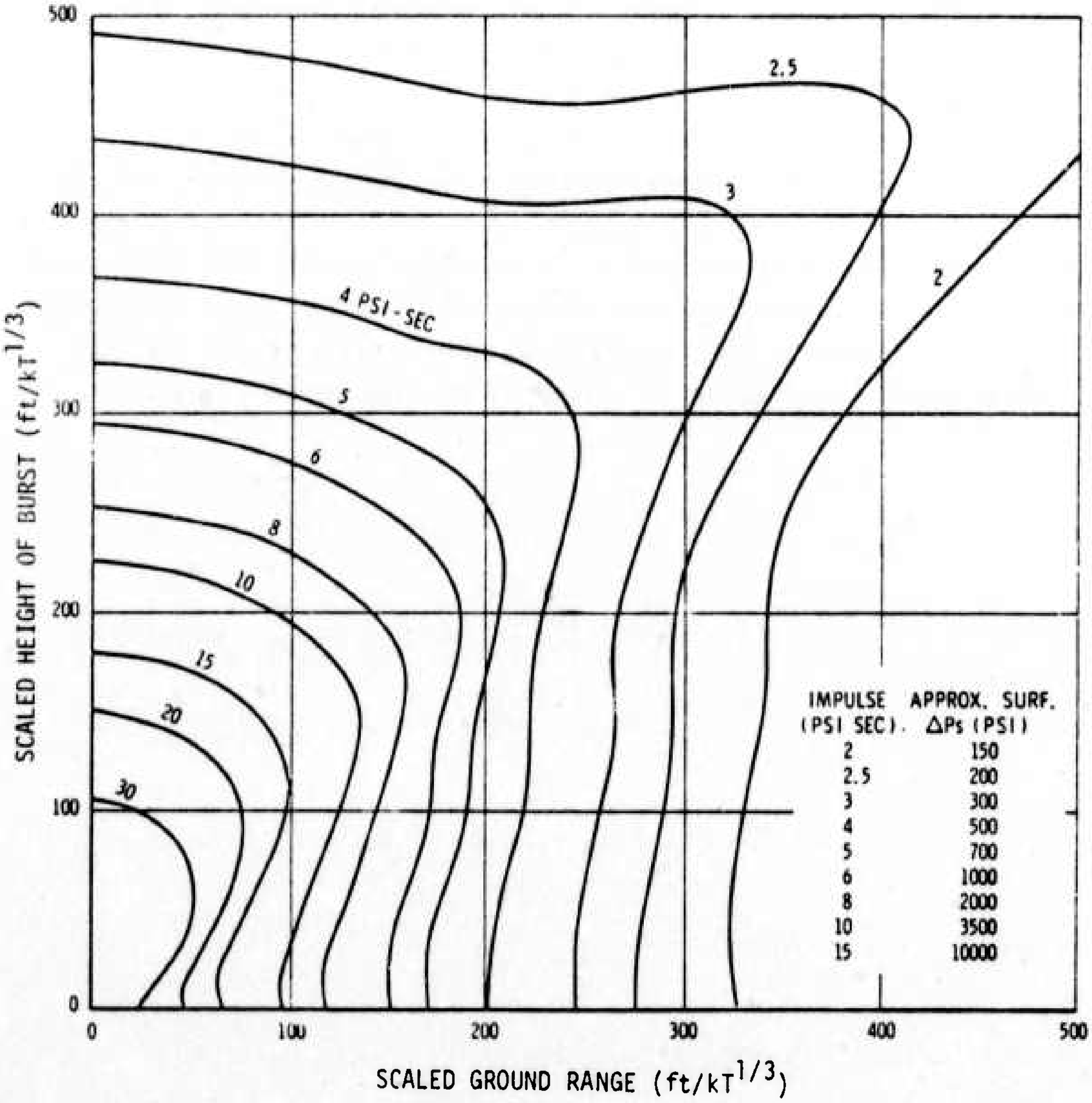

Figure 6. Impulse HOB Curves from Approximate Fit to Analytical Curves (DASA 2506)

The reader is reminded that the failure of non-flush targets which extend above the ground surface may be determined by dynamic pressure loads. Additional research is required to permit construction of dynamic pressure HOB curves in the high overpressure region with good confidence; thus, no attempt was made to include dynamic pressure data in this note.

That same research being conducted by the Defense Nuclear Agency cited in the peak overpressure discussion will treat the impulse question, and will be used to evaluate the conclusion drawn here. The results of this research are needed perhaps more for impulse and waveforms than for peak overpressure since neither nuclear nor HE data permit direct construction of HOB impulse curves. Hopefully, it will also provide information on dynamic pressure impulse useful for assessment of damage to non-flush surface targets.

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